Volume 36 July, 1950 *Number 7*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Gas and Dual-Fuel
Engine
Lubrication

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

TROUBLE-SHOOTING GUIDE

The following are suggestions for locating trouble in Gas and Dual-Fuel Engines.

Ring Sticking

1. Distorted pistons or cylinders.
2. High or low jacket water temperatures.
3. Worn pistons.
4. Worn or weak rings.
5. Insufficient ring side clearance.
6. High cylinder oil feed rate.
7. High crankcase vacuum.
8. High crankcase oil level.
9. Poor quality oil.
10. Continuous overload operation.

Combustion Chamber and Port Deposits

1. Improper air filtration.
2. Wet or corrosive gas.
3. Improper cleaning of fuel.
4. Improper combustion.
5. High cylinder oil feed rate.
6. High crankcase vacuum.
7. High crankcase oil level.
8. Worn or weak rings.
9. Low jacket water temperature.
10. Continuous overload operation.

Ring and Cylinder Wear

1. Improper filtration of air, fuel or oil.
2. Water in fuel or oil.
3. Corrosive fuel.
4. Low oil viscosity.
5. Insufficient oil.
6. Low jacket water temperature.
7. Blow-by.
8. Distorted pistons or cylinders.
9. Frequent cold starts.
10. Excessive piston clearance.

Bearing Wear or Failure

1. Excessive bearing clearance.
2. Insufficient bearing clearance.
3. Misaligned bearings.
4. Distorted crankshaft.
5. Insufficient oil.
6. Low oil viscosity.
7. Contaminated oil.
8. Corrosive oil.
9. Water in oil.
10. Defective bearing construction.

CONTINUED ON INSIDE BACK COVER

TEXACO
REG. T. M.

MORE stationary Diesel horsepower and more Diesel electric locomotives in the United States are lubricated with Texaco than with any other brand.

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

Published by
The Texas Company, 135 East 42nd Street, New York 17, N. Y.
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Vol. XXXVI July, 1950 No. 7

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Gas and Dual-Fuel Engine Lubrication

GAS ENGINES have been used for many years as a source of power in areas where natural or manufactured gas has been available in large quantity. Until recently, however, these areas were confined, for the most part, to southern and western sections of the United States where gas at low cost could be obtained readily from nearby gas and oil fields. Today, gas is being transmitted via pipelines to a far wider area, which means an ever-increasing use of gas as a fuel for internal combustion engines.

Gas engines are built in from about 10 h.p. up to several thousand. They employ spark ignition and the gas can be inducted through a mixing valve or by injection at low pressure depending upon equipment design. It is interesting to contrast this type of operation with that involved in other types of internal combustion engines, such as gasoline engines, mixed cycle engines, diesel engines, gas-diesel engines and dual-fuel engines, as outlined in Table I.

Engines operating on gas, a combination of gas and pilot oil (diesel fuel) or on straight diesel fuel are used in a great variety of applications. The larger engines are the source of power for electricity, compressing, repressuring and cycling operations, sewage disposal, pumping services, chemical processing and drilling operations.

In the automotive field, study is being given to conversion of passenger car, bus and truck engines to burn butane and propane. The use of dual-fuel injection has also been considered for automotive engines.

THE first gas engine was successfully operated in the early 1860's. In 1898, a patent was applied for by Dr. Diesel which envisioned the first gas-diesel or dual-fuel engine. His patent, in part, stated, "The compression temperature of the working mixture does not reach its own ignition temperature but the ignition temperature of a second easier ignited fuel so that an injecting of the latter starts the combustion of the working mixture." Many years passed before such an engine was manufactured and placed in successful use.

Since the last war, the production and utilization of engines capable of burning gas or a combination of gas and liquid fuel have increased at a phenomenal rate. Transmission of natural gas to many parts of the country has facilitated this development and at the same time has enabled the useful consumption of a resource that was heretofore largely wasted. And the end is not yet in sight. More and more engines will be made or converted to burn gaseous fuel and such engines, as a class, will take their rightful place among the more important prime movers.

TYPES OF ENGINES

It is the purpose of this discussion to cover lubrication of two general classes of engines, namely gas engines and gas-diesel and/or dual-fuel engines.

By definition, a gas engine is a spark ignition engine that burns fuel which is normally in a gaseous state rather than fuel which is normally in a liquid state. At the present time, there are many more gas engines in general use than gas-diesel or dual-fuel engines.

Within the general classification of gas-diesel and/or dual-fuel engines, both terms are often used synonymously or interchangeably. Whether gas-diesel or dual-fuel, the engine is a compression ignition unit which can operate either on a com-

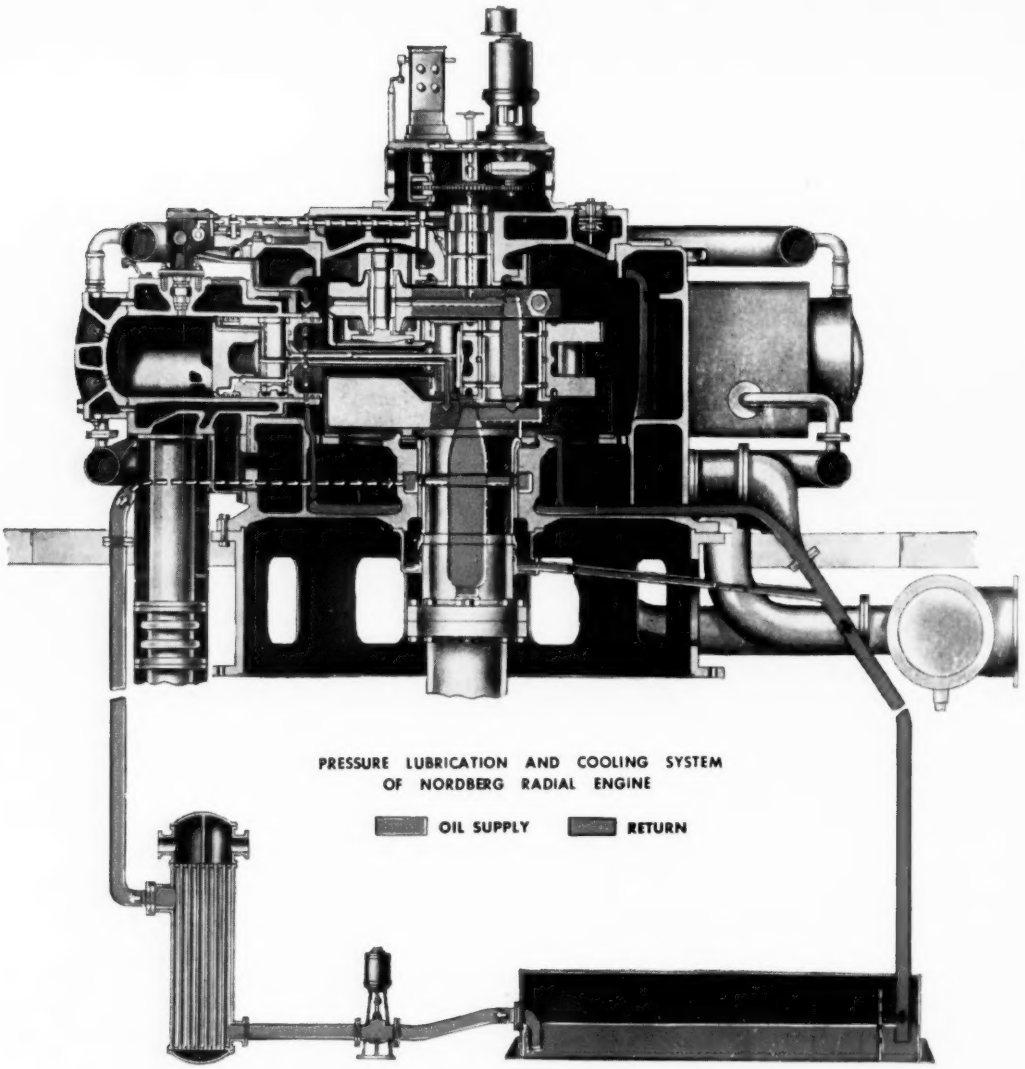


Figure 1 *Courtesy of Nordberg Manufacturing Co.*

bination of gas and pilot oil or as a full diesel engine.

With some engines, it is necessary to shut down and change fuel-handling equipment before a switch from one fuel to another can be made. In such instances, all that is generally required is replacement of the small injectors used for the gas and pilot oil combination with larger injectors for handling diesel fuel. Other engines can be changed from one fuel to another, either automatically or manually, without interfering with operations or load factors. In either case, flexibility of operation is provided to the operator, which is not available with straight gas or full diesel engines.

It is possible to convert some makes and types of gas engines to gas-diesel or dual-fuel engines or to full diesel engines. Likewise, certain types and makes of diesel engines can be altered to operate as dual-fuel or gas-diesel engines or even gas engines. This applies to air injection as well as solid injection engines. Such alterations may involve change of cylinder heads, change of pistons, modification of fuel-handling equipment, change in timing, etc. Engines can be modified to use the least expensive fuel or combination of fuels in any particular area.

DUAL-FUEL OPERATION

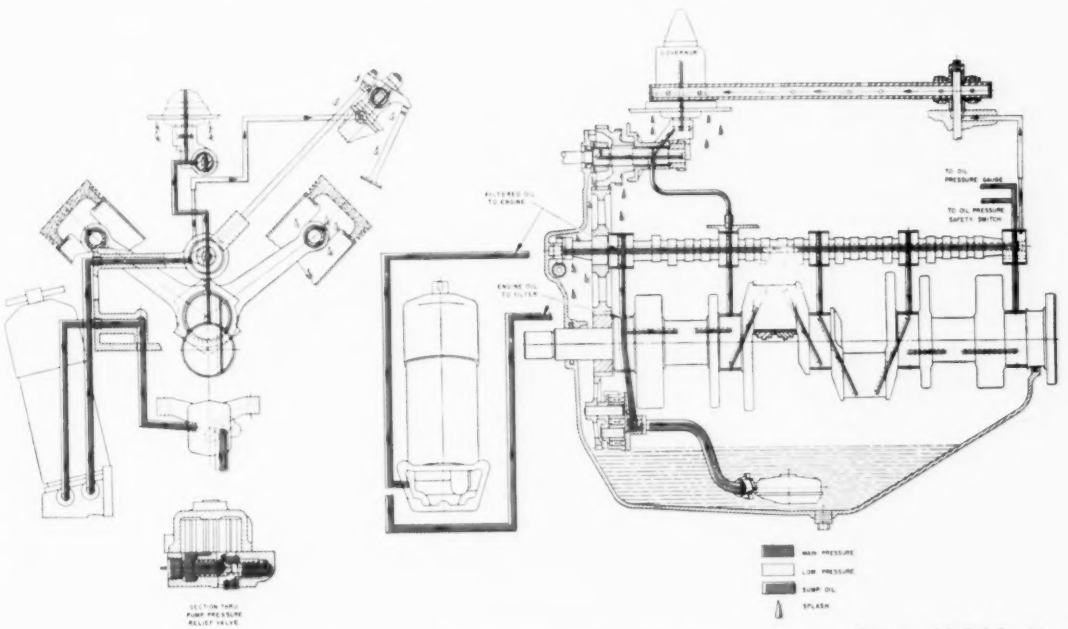
When operating on gas plus pilot oil, the gas-

TABLE I

Classification of Reciprocating Internal Combustion Engines

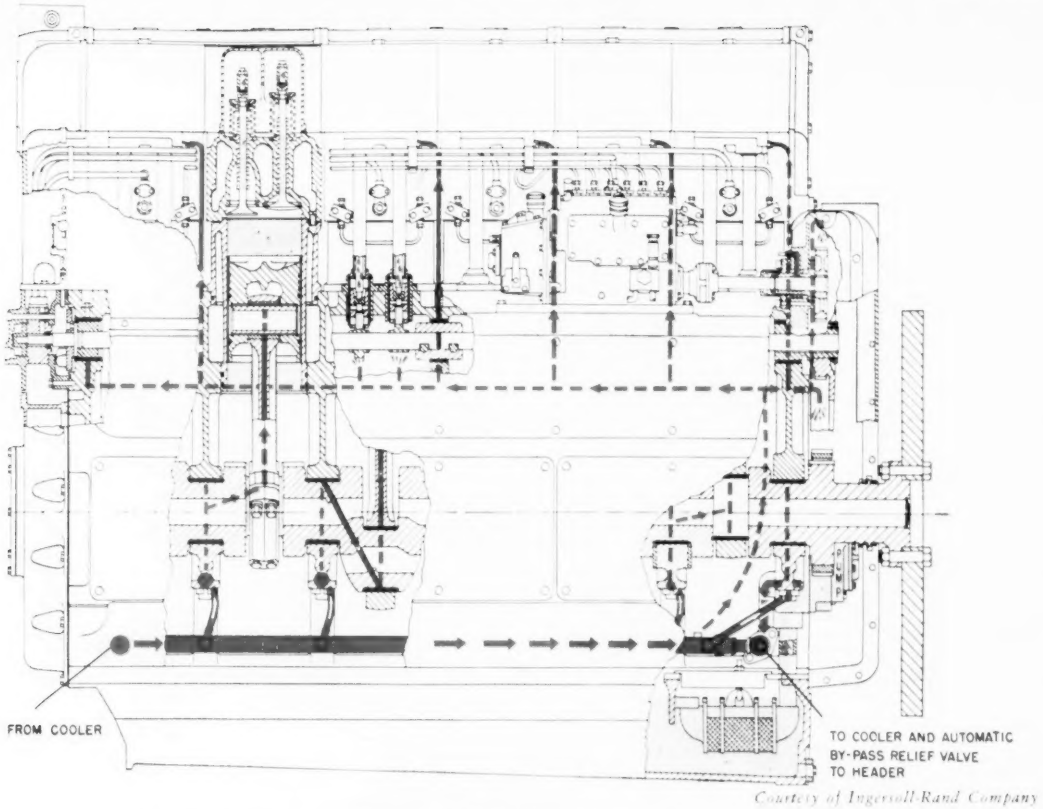
Engine Type	*Fuel Used*	*Induction Method*	*Compression Ratio*	*Ignition Method*
Gas Engines	Gas	Mixing valve or injection	Low	Spark Ignition
Gasoline Engines	Gasoline	Carburetor or injection	Low	Spark Ignition
Mixed Cycle Engines Oil Engines Semi-Diesel Engines	Gasoline Tractor Fuel Diesel Fuel Fuel Oil	Carburetor or injection	Low or High	Spark Ignition Hot Surface Ignition Compression Ignition
Diesel Engines	Diesel Fuel Fuel Oil	Injection	High	Compression Ignition
Gas-Diesel Engines Dual-Fuel Engines	Gas + Pilot Oil or Diesel Fuel	Injection	High	Compression Ignition

diesel or the dual-fuel engine can be adjusted to consume a fixed amount of pilot oil regardless of load. Variation in load is compensated for by the governor increasing or decreasing the amount of gas supplied. Each type of engine can also be set to handle a fixed ratio of pilot oil to gas, the governor increasing or decreasing the supply of both fuels to take care of load variation. Inasmuch as certain of the dual-fuel engines can be automatically or manually switched from one fuel to another, they



Courtesy of LeRoi Company

Figure 2 — Lubrication System of a LeRoi Engine.



Courtesy of Ingersoll-Rand Company

Figure 3 — Schematic diagram showing pressure lubrication lines of an I-R engine.

can be adjusted to operate on almost any percentage of either within maximum and minimum limits. At present, these limits vary from a low of about 5-7% pilot oil to a high of 100%, the latter being required for full diesel operation.

Flexibility of the dual-fuel engine enables an operator to use the lower cost fuel at all times. If gas is available at a BTU cost less than that of diesel fuel, most economical operation is obtained by burning gas with a minimum amount of pilot oil. If, on the other hand, the BTU cost of diesel fuel is less than that of gas, full diesel operation is the most advantageous. If the BTU cost of gas is less than that of diesel fuel, but its availability is limited, the available gas can be burned, the rest of the load requirement being made up by burning pilot oil. The advantages of operating this type of engine in and around oil and gas fields, as well as in pipeline transmission services, are very obvious.

GASEOUS FUELS

From an operating standpoint, the most interesting characteristics of the gas are the heating value, the amount of air required for combustion, the anti-knock value, the pre-ignition tendency, the amount and nature of impurities, and, last but not least, the cost. Most engines operate on natural gas which is mainly composed of gaseous hydrocarbons such as methane, ethane or ethylene, with a few per cent of inactive gases such as carbon dioxide or nitrogen. Gas of this composition will have a heating value of about 1000 BTU per cubic foot and, under ideal conditions, will require about 10 cubic feet of air per cubic foot of gas for complete combustion. Actually, in regular engine operation, an excess of air is needed to insure good combustion. While it is not practical to determine the anti-knock value of gaseous fuels, under prescribed and established test conditions, it is recognized that the value for natural gas is well above 100 octane. In addition, such a fuel will not easily pre-ignite.

The type and character of undesirable products which may enter the engine with the fuel gas are varied. Natural gas is comparatively clean although it may contain rust particles from transmission piping. It may also contain liquid hydrocarbons. Illuminating gas is likewise generally clean. Producer gas usually contains soot and tarry matter as does coke-oven gas. The latter may also carry along with it some undesirable sulfur constituents. Blast furnace gas is almost always contaminated with lime dust, iron oxide and soot. Sewer gas may contain a high

percentage of hydrogen sulfide which can be removed by proper handling. Gas impurities can be eliminated or at least reduced to a minimum by scrubbing or water washing. Unless careful attention is accorded this operation, water may enter the engine along with the purified gas.

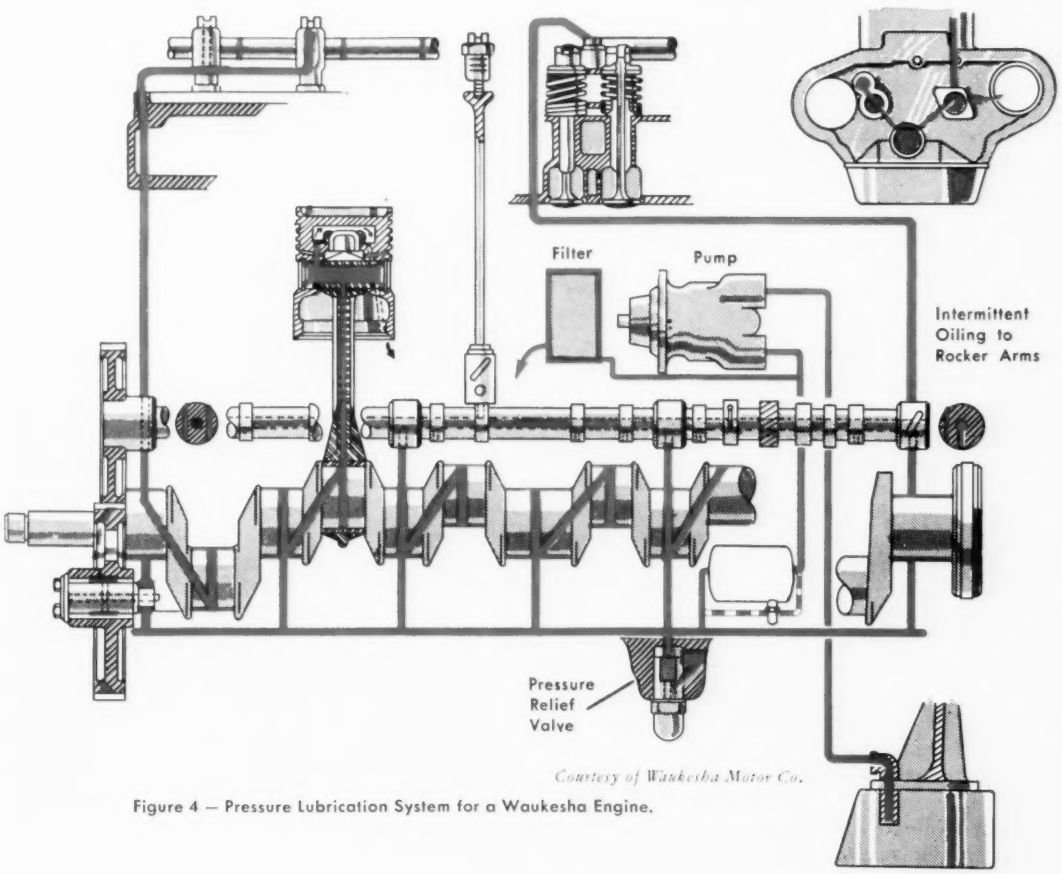
PILOT OIL

Engines operated as gas-diesel or dual-fuel need a certain amount of pilot oil or diesel fuel for purposes of initiating ignition of the fuel-air mixture following compression. The quality of the pilot oil should be comparable to the quality of diesel fuel required to operate the engine satisfactorily as a full diesel. Inasmuch as the pilot oil is only needed for the purposes of ignition, the most important characteristic to consider is ignitability or cetane number. The cetane number should be high enough to provide ease of starting, freedom from combustion knock and freedom from exhaust smoke. If the cetane number is not sufficiently high, not only will there be trouble with starting and mis-firing, but also higher gas and pilot oil consumption will result. Other characteristics such as distillation, carbon residue and sulfur content are of lesser importance although these features should be kept within accepted standards to insure obtaining good combustion and clean engine operation.

LUBRICATION SYSTEMS

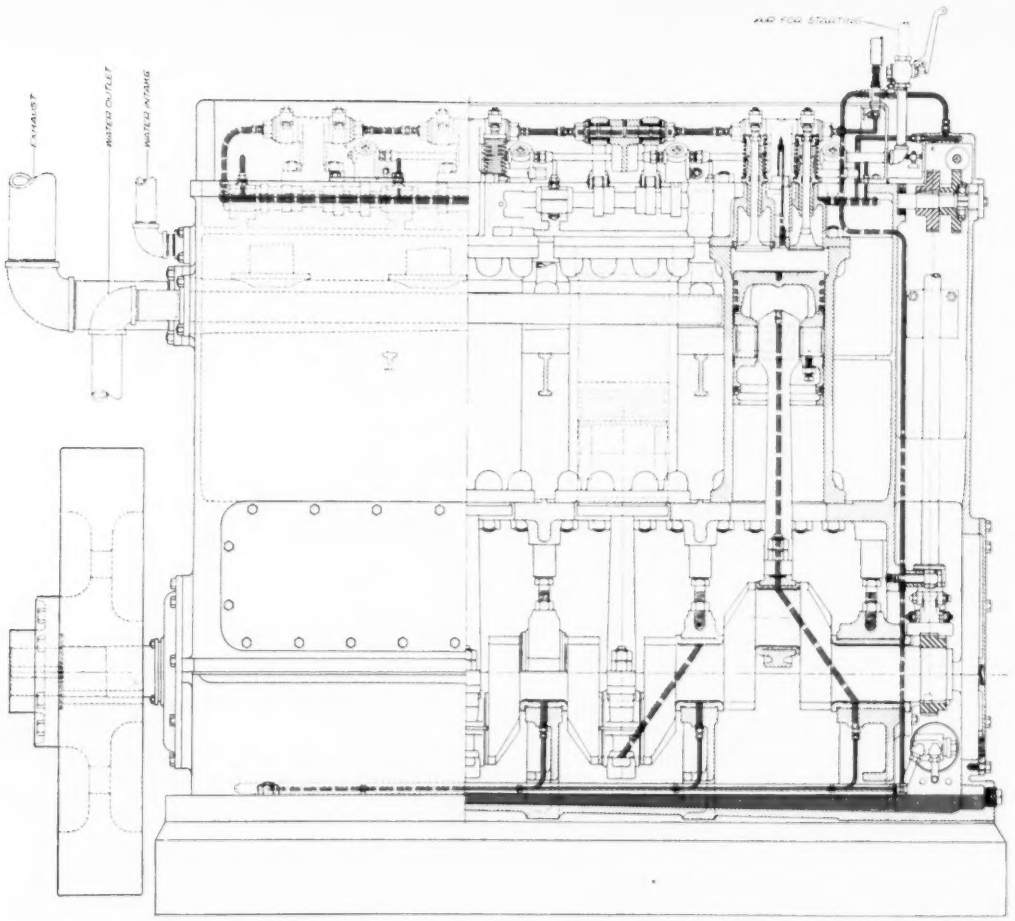
The lubrication systems of gas and gas-diesel or dual-fuel engines are very much the same. With the smaller engines, in pumping, auxiliary and automotive services, and for some of the larger engines, a single lubrication system, combining pressure lubrication and splash lubrication, is invariably used. For most of the larger engines, dual lubrication systems are generally necessary. Pistons, rings and cylinders are separately lubricated through forced feed or sight glass lubricators, generally with new oil, but in some cases with filtered crankcase oil. The former is to be preferred as it insures only, fresh, clean oil reaching these vital engine parts at all times. Piston cooling, bearing, gear and valve lubrication in the larger engines is provided for by circulation of the crankcase oil.

In most engines equipped with dual lubrication systems, there is not complete segregation of power



Courtesy of Waukesha Motor Co.

Figure 4 — Pressure Lubrication System for a Waukesha Engine.



Courtesy of The Bruce-MacBeth Engine Co.

Figure 5 — Lubrication Details of a Bruce-MacBeth Engine.

cylinders from the crankcase. This means that the crankcase is open to blow-by gases and that some of the excess oil from cylinder lubrication will drain into and be mixed with the crankcase or circulating oil. Likewise, a certain amount of crankcase oil will be splashed by crankshaft throws or thrown from crankshaft bearings onto the cylinder walls. From this it is apparent that the crankcase oil has plenty of opportunity to become aerated, to absorb condensible components from blow-by gases, and to otherwise become contaminated with products of incomplete fuel combustion. Consequently, no lubrication system can be complete without adequate provision for purifying or filtering the crankcase oil to remove extraneous contaminants as well as fuel and/or oil oxidation products. At the same time, no lubrication system of any type of internal combustion engine can be complete without adequate means of cooling the crankcase oil. It is impossible to over-emphasize the desirability of using ample and efficient filtering equipment as it means the savings of many dollars in oil maintenance and cost of engine maintenance.

LUBRICATION

Generally speaking, gas and gas-diesel or dual-fuel engines are not too difficult to lubricate. Certainly such engines are easier to lubricate than comparable engines which are operated continually as full diesels. The reason for this is apparent when consideration is given to the fact that combustion is cleaner and more complete when gas is used than when diesel fuel is burned in the combustion chamber. This factor also explains why full load exhaust gas temperatures are lower while operating as a gas-diesel than when operating 100% diesel. The large volume of gaseous fuel compared to the small volume of vaporized liquid fuel results in more thorough mixing of fuel and air and, consequently, more complete burning within the cylin-

der. Accordingly, less carbon and products of fuel oxidation are produced to obstruct ports, lodge in piston ring grooves and contaminate crankcase oil. At the same time, the useful life of crankcase oil filters is definitely prolonged.

There are a number of simple maintenance items which, if followed, will materially improve the overall lubrication of gas and gas-diesel or dual-fuel engines:

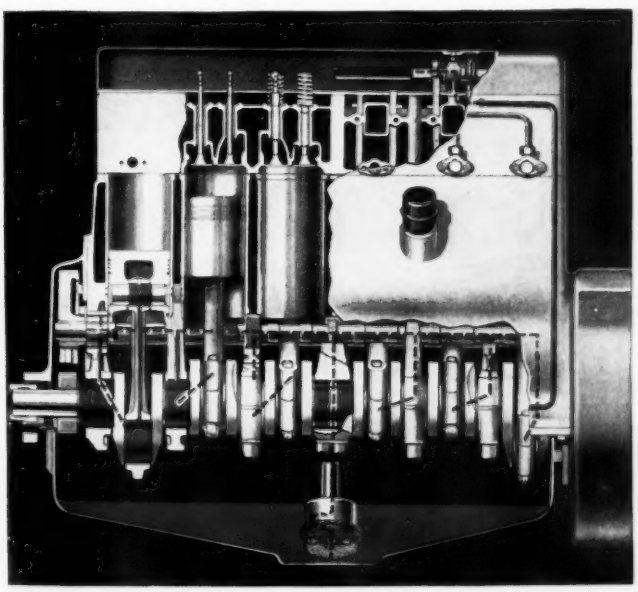
1. Oil feed rate to cylinders should be kept within the limits called for by the engine manufacturer — preferably on the low side. Feeding too much oil to cylinders does not improve lubrication and only promotes ring sticking, port deposits, valve deposits and general lacquering because the excess oil has no way of getting away from the heated surfaces quickly enough. Feeding insufficient oil to cylinders will result in unnecessarily high ring and cylinder liner wear and, in extreme cases, scoring may take place.

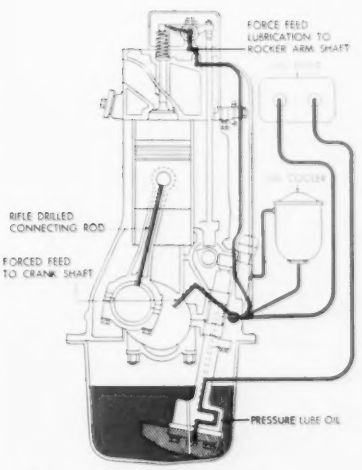
2. Forced feed lubricators should be regularly maintained. They should never be filled to more than ¾ to ⅞ of capacity in order to avoid leakage and consequent wastage of oil. Sight glasses should be cleaned as necessary and new solution installed so that operators can see at a glance that oil at approximately the correct flow rate is passing through to the cylinders. Check valves at the cylinders should be removed and cleaned out at least once a year in order to insure positive delivery of oil to cylinders at all times. It may be necessary to clean these check valves more frequently in cases where crankcase oil is fed through the lubricators to the cylinders.

3. When burning gas, it should be scrubbed as dry as possible, otherwise, fuel valve sticking is apt to occur and needless carbon will accumulate on piston crowns and in the ring belt area. In addition crankcase oil will contaminate more rapidly and spark plug life also may be adversely affected.

4. Engine jacket water temperatures should be carefully watched. The inlet temperature should be maintained at a level of at least 130°F., if possible, with an outlet temperature of some 10°F. higher in order to minimize the chance for low-temperature sludge to accumulate in the crankcase and other cool portions of the engine. A temperature level somewhat higher than this is desirable where water condition permits. In areas where hard water is all that is available, chemical treatment should be carried out to prevent scale formation and salt deposits in water jackets and, in particular, around cylinder liners.

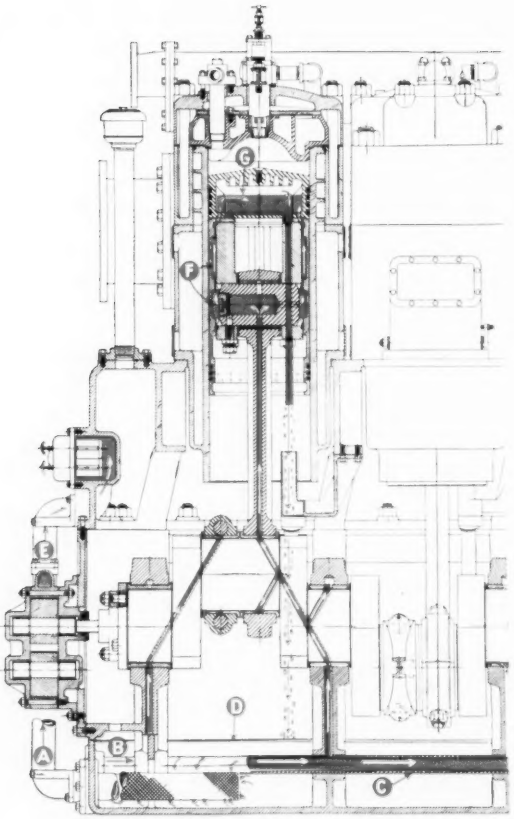
5. For best crankcase oil service, oil temperatures should fall within the range of 140-180°F. Operating with temperatures much below this level is undesirable, not only because of the possibility of forming low-temperature sludge, but also because the efficiency of oil filters drops off rapidly as oil temperatures are lowered. This is particularly true of filters or purifiers using adsorbtive materials like Fullers earth for filtering purposes. On the other hand, operating with too





Courtesy of The Buda Company

Figure 6 — Diagrammatic Views of the Buda Engine Lubrication System.



Courtesy of Clark Bros. Co., Inc.

Figure 7 — Lubrication System of a Clark Engine.

high an oil temperature is not good for the oil. Not only is oxidation accelerated but also thickening or viscosity build-up due to evaporation loss becomes more pronounced. Piston cooling oil passages should be open to insure positive oil flow at all times. Otherwise, the oil will carbonize in the piston head cavity, impairing heat transfer and unnecessarily deteriorating the crankcase oil. Oil cooler condition should be investigated if crankcase oil temperatures climb appreciably above 180°F. level.

6. On many engines, the crankcase is maintained under a slight vacuum in order to prevent leakage of oil from around the crankcase base and crankcase doors. It is important that the vacuum be no more than about ¼-½" of water; otherwise, excessive oil (and oil vapor if crankcase oil temperatures are unusually high) will be pulled out of the crankcase into the scavenging system. Not only is high oil consumption the result but also, if there is no trap in the scavenging line, carbonaceous deposits will form in the scavenging ports, as well as in the combustion chamber. There is also the possibility of causing piston rings to stick. Another consideration is the fact that crankcase explosions are less apt to occur under conditions of low crankcase vacuum as compared to high crankcase vacuum.

7. Adequate and efficient purification of crankcase oil is most important. The installation of a sight glass in the outlet line from the oil purifier is highly recommended as it will enable operators readily to observe oil cleanliness, rate of oil flow, and about when filter cartridges should be changed. The condition of the crankcase oil should be checked by a competent laboratory at regular intervals for contamination and degree of oxidation. Such analyses, along with proper recommendations, will materially improve overall operations and will enable operators to obtain the maximum useful life from their oil.

LUBRICATING OIL

Two types of oil are used to lubricate gas, gas-diesel and dual-fuel engines. For the smaller, high-speed engines, where oil temperatures are relatively high and crankcase capacities are relatively small, the so-called heavy-duty type oil is preferred. Such oils contain chemical additives which improve oxidation stability, dispersion and detergency characteristics. Engines requiring the use of heavy-duty oil, and lubricated with this type of oil, will remain cleaner, will require less maintenance and will operate more efficiently over a longer period of time than when lubricated with other types of oil. Certain of the heavy-duty oils possess the property of rust prevention which is particularly desirable for engines operated in intermittent or seasonal service.

The larger slow- and medium-speed engines with dual lubrication systems can be successfully lubricated with good quality straight mineral oil or additive type oils. Experience has shown that the crankcase oil should be of the straight mineral type, providing it is not also used for cylinder lubrication. It also has been proved that best overall crankcase lubrication is obtained by using a highly-refined,

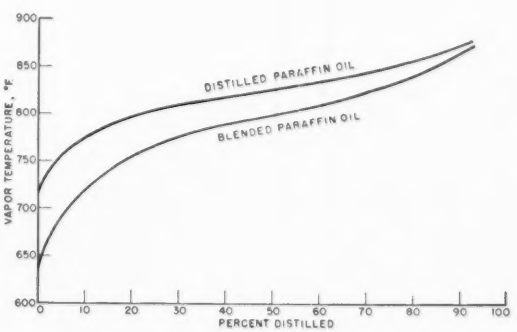
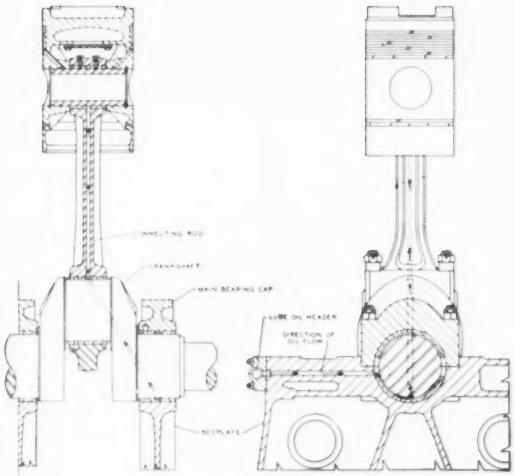


Figure 8 — Comparison of Vapor Temperatures of Distilled and Blended Paraffin Oils.



Courtesy of The National Supply Company

Figure 9 — Schematic Diagram Showing Method of Lubricating Crankshaft Bearings and Piston Assembly of a Superior Engine.

distilled, paraffin base oil. In order to prolong its useful life, the oil should be filtered or purified through an activated medium such as Fullers earth or alumina to remove contaminants and products of oxidation as promptly as they accumulate. One of the main reasons for recommending highly paraffinic, distillate type oils for crankcase lubrication is to overcome the problem of thickening or viscosity build-up caused by evaporation losses. Distilled oils, being cut to grade, have much flatter distillation curves than the same grades of oils manufactured by blending procedures. Figure 8 illustrates the difference between a distilled paraffin base oil and a blended paraffin base oil with regard to distillation characteristics.

For practically all engines of 50 h.p. per cylinder and above, the type of oil required for piston and cylinder lubrication is the same as that used in the crankcase. Straight mineral, paraffinic, distillate oil is preferred to blended paraffinic, residual oil because more carbon will form with the latter in ports and in the combustion chamber. The former is also preferred to distilled naphthene base oil to insure adequate protection against piston ring and cylinder liner wear. Admittedly, more combustion chamber and port carbon is apt to form with distillate paraffin base oil than from distillate naphthene base oil, but this feature can be kept under good control by being sure that no more than the required amount of oil is fed to the cylinders.

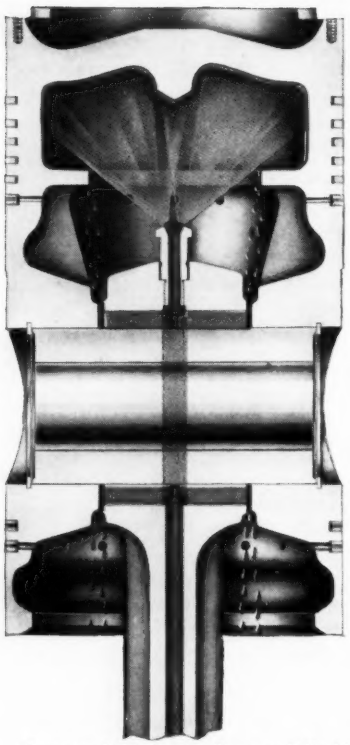
Heavy-duty type oil also can be used for piston and cylinder lubrication. In practically all cases, however, the use of oil of this quality is not required. Wherever used, there are a few problems associated with its handling that must be considered. Strict precautions have to be taken to see that no more than is absolutely necessary is fed through the lubricators to the cylinders; otherwise, deposits will form and fouling of gas engine spark plugs can occur. In addition, the additives used in heavy-duty oils are sensitive to water. Some of these additives have a dissolving effect whereas others may be precipitated out of the oil. In either case, carry-over or clouding of lubricator solution will occur, necessitating more frequent cleaning of sight glasses than if straight mineral oil were used. It is possible to alleviate this difficulty by using lubricator solutions which will not react with the additives in the oil.

Straight mineral, paraffin base, distillate oil or heavy-duty oil can be used in those engines that circulate crankcase oil through lubricators for piston and cylinder lubrication. For most installations, the use of straight mineral oil is preferred. Where heavy-duty oil is used, the oil has to be filtered through some inactive medium, such as cellulose or waste, rather than activated clay; otherwise, undesirable additive removal will occur.

MISCELLANEOUS LUBRICATION

On many of the larger engines, rocker arms, rollers and other exposed assemblies are separately lubricated with either grease or oil to insure positive lubrication at all times. This phase of engine lubrication is important and should not be neglected. Lubrication of external engine parts should be properly scheduled so that problems associated with under-lubrication or over-lubrication are not encountered. Under-lubrication will, of course, cause unnecessary wear of bushings, shafts, rollers, tappets, etc., whereas over-lubrication will promote deposit formations, resulting in sluggish operation of these parts.

Figure 10 — Stuck Fuel Valve Caused by Carbonization of Wet Gas.



Courtesy of Worthington Pump and Machinery Corp.

Figure 11 — Worthington's Oil Cooled Piston Showing Path of Oil Travel.

On some engines, provision is made for the use of upper cylinder lubricant. The necessity of this is a debatable question. Some operators feel it is required for best operation while others have found from experience that it is not necessary. About all that can be said is that, where practiced, overlubrication should be guarded against. Otherwise, deposit problems such as port plugging, ring sticking, valve sticking and possibly spark plug fouling may be experienced.

SPARK PLUGS

Heavy-duty, slow-speed gas engines, burning either natural or artificial gas, require spark plugs capable of providing exceptionally long life. It is not unusual for large units in central power generation, compression, cycling and pumping services to run six months to a year or more without interruption. Due to the inherent characteristics of natural gas which averages 60-90% or more methane, depending upon the source, some investigators report that substantially more energy is required for ignition than for other heavier hydrocarbon fuels like gasoline and diesel fuel. The higher energy requirement necessitates the use of a more intense spark which means that the electrodes of the normal type of automotive spark plug will burn much too rapidly to provide satisfactory service over any reasonable operating period. For this reason, gas engine spark plugs generally have relatively large electrode surfaces for transfer of the spark.

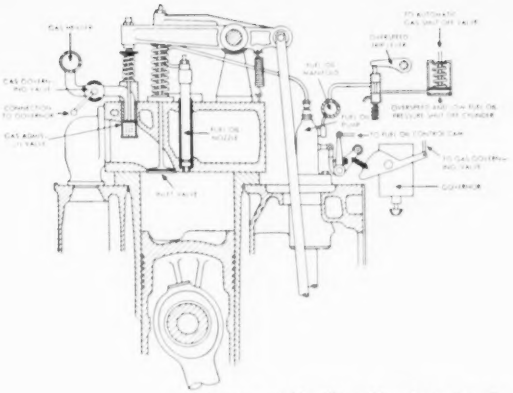
Some gas engines must operate on raw gas containing appreciable amounts of sulfur and other corrosive ingredients. During combustion, "sour gas", as it is known, forms sulfurous acids which have a corrosive action on most engine parts, including the plug electrodes. For such applications, the chemically-inert nature of the platinum electrode plugs has been well suited.

CRANKCASE EXPLOSIONS

It is well known that crankcase explosions can and do occur in practically all types of internal combustion engines. In smaller engines, because of the small size of the crankcase, this problem is not too important inasmuch as the force developed as a result of an explosion is generally insufficient to cause any major damage. In larger engines with their much larger crankcases, however, the force of an explosion is multiplied many times and serious damage to engine, property and operating personnel has often occurred.

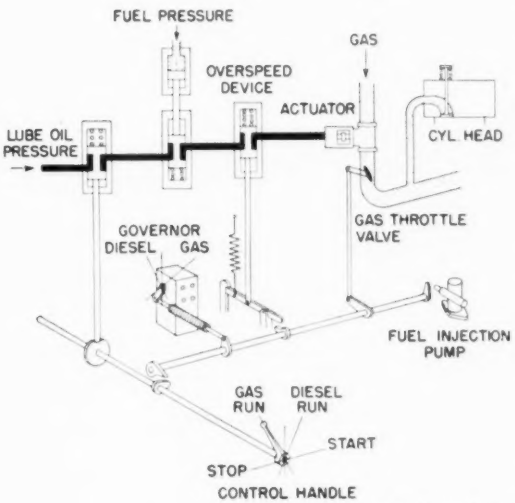
Courtesy Nordberg Manufacturing Company.

Figure 12 — Path of oil circulation to knuckle and piston pins for a Nordberg two-cycle oil and gas burning engine.



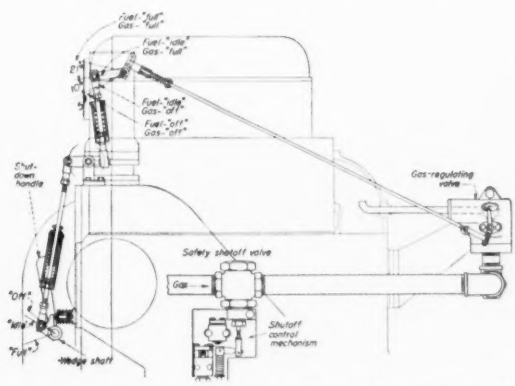
Courtesy of Nordberg Manufacturing Co.

Figure 13 — Schematic Arrangement of Gas and Oil Fuel Details for Nordberg Duafuel Engine.



Courtesy of Fairbanks, Morse & Co.

Figure 14 — Schematic Arrangement of Gas and Oil Fuel Details for Fairbanks Morse Dual-Fuel Engine.



Courtesy of The Cooper-Bessemer Corp.

Figure 15 — Schematic Diagram of Gas and Oil Fuel Controls for a Cooper Bessemer Gas-Diesel Engine.

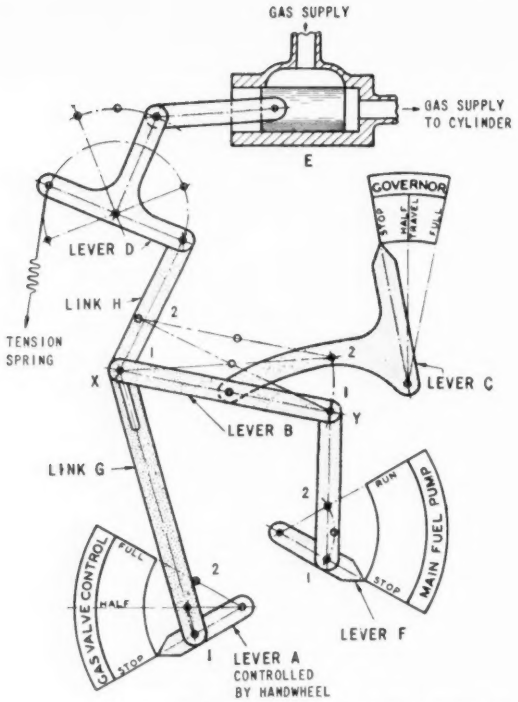
A study of available information on crankcase explosions reveals that, in all cases, explosions are caused by ignition of vapors in the crankcase by one or more overheated engine parts or flame torching past a piston assembly. The crankcase atmosphere of an engine operating under normal conditions consists primarily of air prolifically charged with globules of oil of many different particle sizes ranging from large to microscopic droplets. Under these conditions, there is no appreciable quantity of oil vapor present inasmuch as the vapor pressure of any crankcase oil at 150-200°F. is only of the order of 5-10 microns. At the flash point temperature of the oil, 375-450°F., there can be no more than approximately 1% oil vapor present in the crankcase atmosphere.

In the event a hot spot develops within the confines of an engine crankcase, its temperature being above the spontaneous ignition temperature of the oil in use, the oil particles in the vicinity of the hot spot will vaporize and may form an inflammable mixture that could spontaneously ignite to cause an explosion. Similarly, if the oil particles come in contact with an open flame, ignition can occur which may propagate throughout the mixture.

Investigations have shown no appreciable effect of lubricating oil type or viscosity on crankcase explosions. Accordingly, changing from one oil to another will accomplish little in the way of preventing their occurrence. A number of operating and maintenance items, however, do have a bearing on the matter, and there is a possibility of alleviation or perhaps elimination of explosions by carefully studying their relationships with the problem.

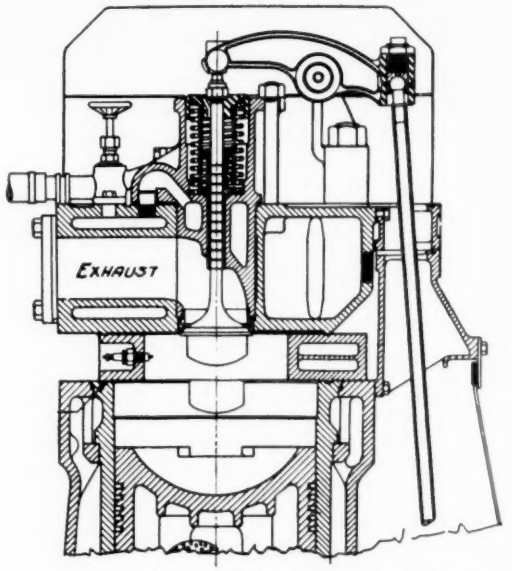
It is generally recognized that the minimum hot spot temperature required for initiating explosions increases very rapidly under lean mixture conditions, i.e., a high ratio of crankcase ventilating air to oil droplets. As a matter of fact, after reaching and going beyond the lean limit of combustion, it is not possible for an explosion to take place no matter how high the temperature may go. Likewise, it is known that a similar situation exists beyond the rich end of the inflammable range. The huge quantities of air required to provide a mixture too lean to burn, along with the probability of richer pockets being present at various points throughout the crankcase, indicate that endeavoring to prevent crankcase explosions by this procedure is not very sound from a practical standpoint. There may be cases, however, where it might be possible to operate in the overrich range by suitable reduction or complete elimination of crankcase ventilating air. Certainly it would seem desirable for operators of existing equipment to exclude air from entering the crankcase wherever possible or practicable.

Limited investigations have indicated that it might be possible to reduce the chance of a crank-



Courtesy of Worthington Pump and Machinery Corp.

Figure 16 — Diagram of Governor Linkage for Worthington Dual-Fuel Engine.



Courtesy of Chicago Pneumatic Tool Company

Figure 17 — Cylinder Head Assembly for a Chicago Pneumatic Gas Engine.

case explosion occurring by lowering the temperature of the crankcase oil and, in particular, that of the crankcase atmosphere. How much can be accomplished by this line of approach is open to question. If consideration is given to its trial, it should be done with the realization that factors adversely affecting lubrication may be introduced. These include formation of low-temperature sludge in the crankcase, reduction in oil filter efficiency, and possible impairment of lubrication.

A third method of attack that might be considered is the possibility of directing oil throw-off and splash, in so far as possible, away from striking surfaces which, from experience, are apt to become overheated. Such an approach obviously involves rather drastic baffling and other devices, and their design would have to be worked out in some detail for each particular installation. In any such undertaking, the fact that suitable quantities of oil must be directed to all sliding surfaces, for obvious reasons, should not be overlooked.

Another feature of crankcase explosions which deserves careful scrutiny is the fact that there is a definite, measurable interval between the time when an engine part begins to overheat, or a flame begins to burn through a piston or between the piston and cylinder wall, and when an explosion actually occurs. Scoring of a piston and/or cylinder wall, for example, may proceed for two, three or more hours of operation before one or more surfaces become hot enough to cause ignition of the crankcase atmosphere. This suggests the possibility of using devices for measuring changes in temperature, crankcase pressure, crankcase air flow, etc., installed in such a way as to automatically shut down an engine when variations exceed safe limits.

SUMMARY

Because of good combustion, engines operating on gaseous fuel are easier to lubricate than comparable engines burning liquid fuels such as gasoline or diesel fuel. Likewise, gas-diesel or dual-fuel engines, while operating on gas with only a small amount of pilot oil, are more easily lubricated than the same engines when burning a high percentage of diesel fuel or diesel fuel exclusively. Consequently, for best overall lubrication, each installation should be considered separately and the selection of oil type should be guided by the kind of fuel being burned. A competent lubrication engineer can be very helpful in this regard.

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TROUBLE-SHOOTING GUIDE

Spark Plug Failure

1. Wet or corrosive gas.
2. Hot or cold plug.
3. Unsuitable plug design.
4. Improper combustion.
5. Excessive oil reaching combustion chamber.
6. Improper air filtration.
7. Improper oil filtration.
8. Improper timing.
9. Improper plug maintenance.
10. Continuous overload operation.

High Oil Consumption

1. High cylinder oil feed rate.
2. High crankcase vacuum.
3. High crankcase oil level.
4. Leakage.
5. Worn or stuck rings.
6. Ineffective oil ring control.
7. Worn pistons or cylinders.
8. Excessive bearing clearance.
9. High oil pressure.
10. Low oil viscosity.

High Oil Temperature

1. Clogged oil cooler.
2. Clogged oil lines.
3. Sludged crankcase.
4. Continuous overload operation.
5. Dirty water jackets.
6. Overheated bearing.
7. Incorrect oil viscosity.
8. Insufficient oil in sump or crankcase.
9. Insufficient oil circulation.
10. Improper timing.

Lack of Power

1. Improper combustion.
2. Insufficient air.
3. High back pressure.
4. Low fuel heat content.
5. Low compression pressure.
6. Leaking exhaust valve.
7. Tight bearings.
8. Improper lubrication.
9. Leaking injectors.
10. Late timing.

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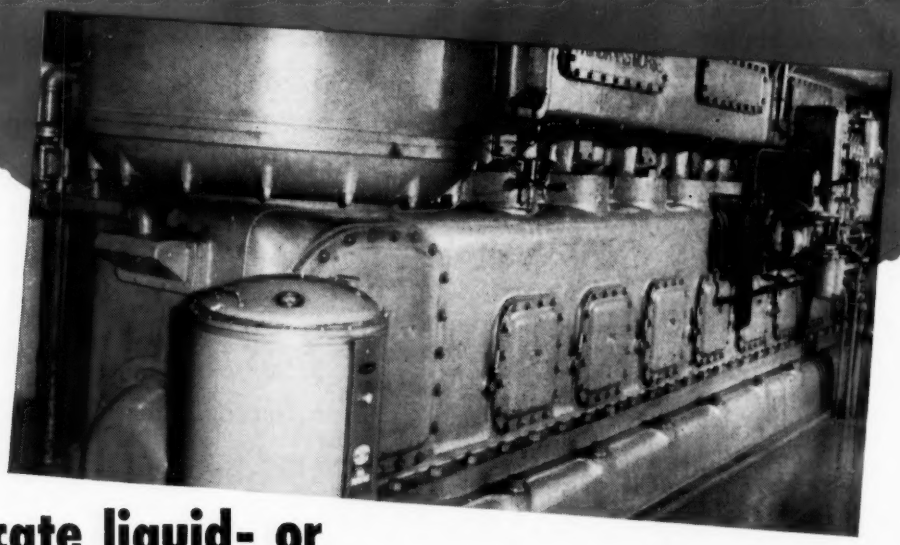

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